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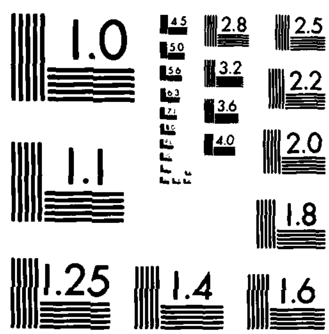

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TEAM PERFORMANCE WITH LARGE AND SMALL SCREEN DISPLAYS

CLIFFORD E. BROWN
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HARRY G. ARMSTRONG AEROSPACE MEDICAL RESEARCH LABORATORY

JUNE 1985

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This report has been reviewed by the Office of Public Affairs (PA) and is releasable to the National Technical Information Service (NTIS). At NTIS, it will be available to the general public, including foreign nations.

The voluntary informed consent of the subjects used in this research was obtained as required by Air Force Regulation 169-3.

This technical report has been reviewed and is approved for publication.

FOR THE COMMANDER

CHARLES BATES, JR.
Director, Human Engineering Division
Air Force Aerospace Medical Research Laboratory

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(U) Large displays are common in modern command centers, yet the rationale for their use is typically weak. A literature search revealed little previous work comparing performance of teams with large group displays versus individual CRT's. The most applicable previous studies used static tasks and photographic projection systems. The study described here used a complex, dynamic task which required extensive interaction between members of three-person teams to achieve best performance. A comparison was made between the performance of three-person teams viewing either one large screen display or three individual CRT's. Results indicate that display size did not strongly affect team performance, although there were differences in the details of task performance that are attributable to display variables.

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PREFACE

This research was conducted at the Harry G. Armstrong Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base, Ohio, under the auspices of the C^3 Operator Performance Engineering (COPE) program as part of Program Element 62202F, Project/Task/Workunit 7184/27/03. We, the authors, gratefully acknowledge the support of the following people:

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INTRODUCTION

Background and Rationale

In command, control, and communications (C^3) systems a performance team is frequently required to assess symbolically presented information and make decisions about the best course of action to take in a dynamic, time-stressed setting. Although each individual in the team may have functions which can be performed alone, additional tasks may require the joint effort of several team members. In such a multiperson, multitask environment, the successful integration of team members' time and effort is crucial for optimal team performance.

Recent technological developments have made it possible to produce high-fidelity, full-color, large screen displays of dynamically generated computer graphics. Whether such displays would be of benefit to a performance team is the central focus of this investigation. Specifically, a comparison is made between the performance of three-person teams viewing either one large screen display or three individual CRTs. In either case, the same dynamic graphic information is provided and several other potentially important variables are controlled (e.g., seating arrangement) or systematically manipulated (e.g., time stress).

Little research exists which has compared team performance using large and small screen displays. Smith and Duggar (1964, 1965) compared team performance with large and small screen static, monochrome displays using a simple search and counting task. Although large screen displays resulted in 15% faster performance than small screen displays without differences in error rate, this difference in speed may be an artifact of the particular procedure used. Specifically, problem information was presented on a large or a small screen (depending on treatment condition), but team performance feedback information was displayed on a large screen regardless of the treatment condition (see Smith & Duggar, 1964, Figures 1 & 2). Therefore, differences in team performance speed attributed to screen size could simply reflect whether problem and feedback information were the same size and side-by-side (as in the large screen condition) or a different size and five feet apart (as in the small screen condition).

The present study differs from Smith and Duggar's in many respects. First, problem information and feedback are presented together on the same screen, whether large or small. Second, full color displays are used. Third, the task developed for the study is cognitively complex, dynamic, and requires team coordination and integration for optimal performance: characteristics typical of systems which would be most likely to benefit from sophisticated computer generated graphics.

The Team Resource Allocation Problem (TRAP)

The team research allocation problem (TRAP) developed for this study is an extension of an experimental paradigm used by Pattipati, Kleinman, and Eprath (1982) to develop a Dynamic Decision Model (DDM) of human task

selection in a multitask environment. In their research, individual subjects seated before a CRT observed rectangular boxes moving across the screen in several different rows. Each box represented a task which the subject could process by pressing a push button corresponding to the box's row on the CRT. Since many boxes crossed the screen in different rows concurrently, not all of the boxes (tasks) could be processed. Instead, the subject chose particular tasks for processing based on various manipulated task characteristics (i.e., reward value, required processing time). Experimental studies revealed that subjects' performance was sensitive to manipulations of task characteristics and consistent, overall, with the DDM. Their success with the experimental paradigm in studying individual task selection performance encourages its extension to the study of team performance. In addition, recent reviews of group problem solving and team performance (Goldin & Thorndyke, 1980; Hackman & Morris, 1975; Hill, 1982) reveal a need for experimental paradigms which permit systematic exploration of dynamic group decision making. Issues related to effective allocation of team resources in a dynamic, multitask environment have not been adequately addressed experimentally, in spite of the clear recognition of their importance.

The particular TRAP used in the present research requires members of a three-person team (persons A, B, and C) to work together to accumulate as many points as possible by processing tasks. Each task requires a particular team member (A, B, or C) or some combination of team members (AB, AC, BC, or ABC) to process it to earn a specific number of points. Since more tasks are available for processing than can possibly be processed by the team members, coordination of their selections is required to obtain a high score.

Tasks not only differ with respect to the workers required for processing, but also with respect to their point value, which depends on the tasks' color and shape. While a task's value in relationship to its color is simple (red tasks are worth more than blue tasks), the task's value in relation to its shape is more complex: one-person tasks (A, B, and C tasks) are worth more if they are circles than if they are triangles; three-person tasks (those requiring simultaneous processing by all three team members, ABC tasks) are worth more if they are triangles than if they are circles; and two-person tasks (AB, AC, and BC tasks) are unaffected by shape. Therefore, while a task's color is an easily generalized attribute, a task's shape is meaningful only when analyzed along with the required number of workers for the task. Table 1 presents the tasks and their point values.

In order to perform well, team members must analyze the tasks that are currently available to them and select those tasks for processing which earn the team the most points. Success depends not only on choosing tasks of high value, but also choosing them in a coordinated fashion. For example, person A may be able to individually process a red circle worth five points or work with person B to process a red triangle worth eight points. The correct choice for the team would depend on the additional task options available to team members at that time. In fact, a simple model of team decision making, which examines the available task options and chooses those which maximize the team's score, serves as a useful standard of comparison for actual team performance.

TABLE 1. Task Point Values for the Team Resource Allocation Problem

One-Person Tasks (A, B, or C)	BLUE	RED	or	BLUE	RED
Point Value	1		3		5

Two-Person Tasks (AB, AC, or BC)	BLUE	or	BLUE	RED	or	RED
Point Value		4			8	
(Per Person)		(2)			(4)	

Three-Person Tasks (ABC)	BLUE	RED	or	BLUE	RED
Point Value	3		9		15
(Per Person)	(1)		(3)		(5)

Research Overview

The present research used a TRAP to compare team performance on large and small screen displays. The problem confronting each three-person team was to coordinate its use of resources, the processing capabilities of the individual team members, in order to obtain the highest possible score. The computer generated graphic display was colorful, meaningful, and operated dynamically with the real-time actions of the participants; it emphasized cognitive assessment and team coordination.

An initial one-hour team training session familiarized participants with the TRAP, their push-button response boxes, and the graphics displays (see Figure 1). During this session both the large screen display and the three individual CRTs were operational, simultaneously presenting identical information. During each of the four subsequent one-hour test sessions, either the large screen or the small screen displays were operational. For four teams the large screen was used during the first and third sessions, while for the remaining four teams the large screen was used during the second and fourth sessions. Therefore, all eight teams were tested twice under each display condition.

SECTION 2

METHOD

Equipment

The large screen display generator was a General Electric Model PJ-5150, Professional Large Screen Projector. It uses a full-color, oil film light valve projection system, and has resolution minimum of 750 horizontal x 650 vertical, with a 1023 line, 60 frames per second scan standard. The rear projection screen was a Phoenix, Inc. Model XX. The large display image size used was 35" high x 49.5" wide, with a .75" character height and with circle diameters of 1.25". The large display bottom line was 39" off the floor, with subjects' eye height of approximately 45" - 50", and 105" from the screen.

The three individual CRTs were Conrac Model 7211, RGB Raster Scan Color Displays. The 13" diagonal displays were 7.92" high x 10.80" wide, with resolution of 921 horizontal x 739 vertical pixels, and 40MHz video bandwidth. Subjects were approximately 18" from the CRTs, and characters were .19" high and circle diameters were .25".

The graphics system utilized was from Aydin, Inc. Custom-made laboratory response boxes were integrated into the system. Throughout the study subjects were seated as shown in Figure 1, with the end subjects approximately 58" apart.

Subjects

Subjects were 24 paid volunteers between the ages of 18 and 30 years, with 20/20 corrected vision and normal color vision. Each of the eight teams consisted of one female and two males.

Procedure

During the one-hour training session, participants were randomly assigned to their seating position, and designated (from left to right) person A, B, and C, respectively. They maintained that position and designation throughout the study. Subjects were given thorough instructions which described the TRAP, discussed features of the display (see Figure 1), told them how to use their response boxes, and presented the rules determining the point value of tasks.

The instructions emphasized that they were to work as a team to accumulate as many points as possible, and that points were earned by processing tasks which were represented by blue and red triangles moving across the screen. They were told how only a particular worker, or combination of workers, could process a task and that this information was depicted on the display. Other display information was also discussed: accumulated points; workers' status (free, waiting, or time until free); task information (time before leaving screen, point value, status). It was explained that all references to time on the display were in time units (TUs), the value of which (e.g., 15 or 30 seconds) would vary from trial to

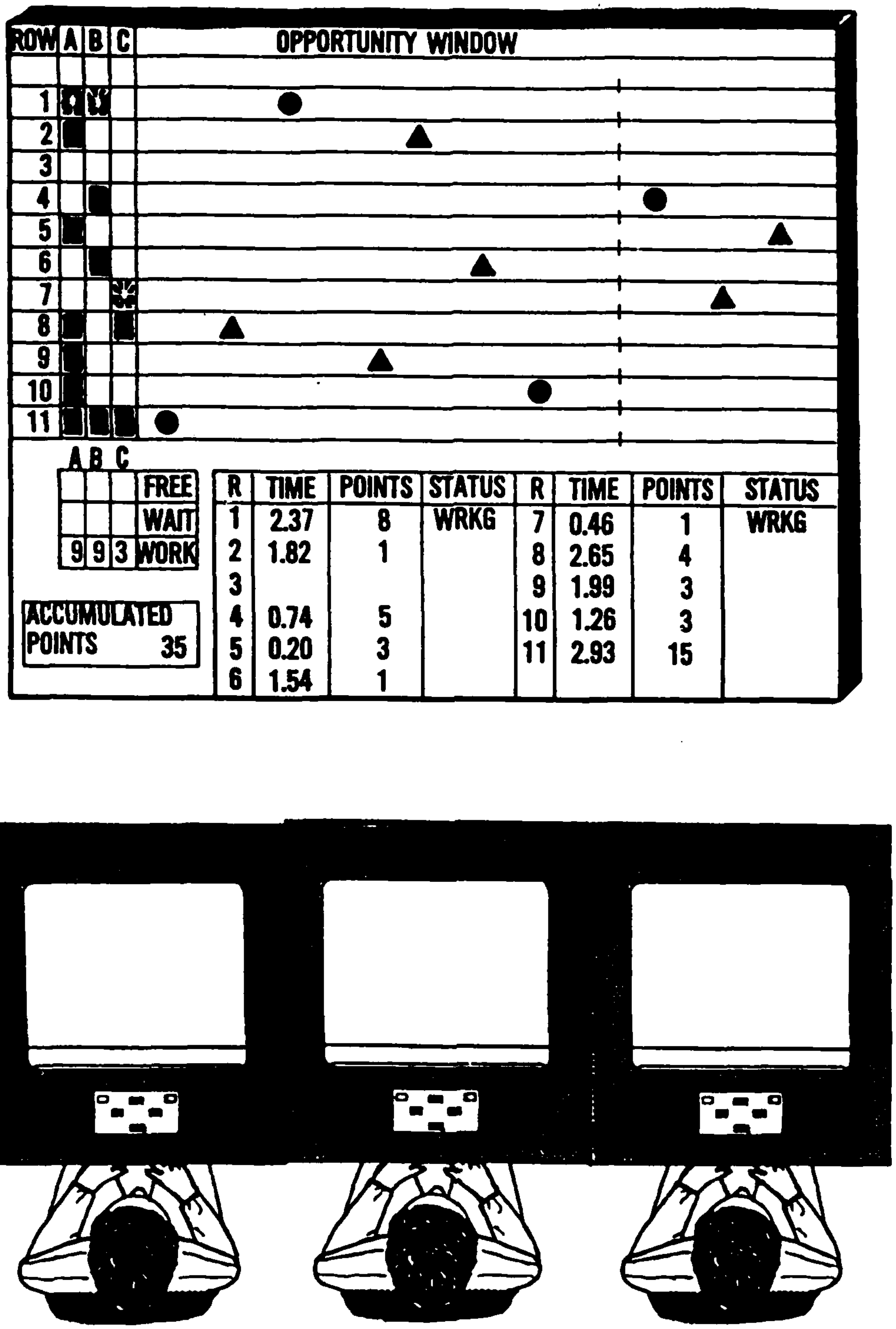

FIGURE 1. Experiment Configurations

(Large display drawn so that task is visible)

trial. Since it took one TU to process each task (regardless of the required workers, color or shape), and three TUs for a task to cross the screen; a task had to be started while within the "opportunity window" in order to be completed.

To ensure participants' understanding of the point values of the tasks, a short test was administered by the experimenter during the training session, and at the start of each subsequent test session. In those rare cases when an incorrect answer was written, the experimenter simply asked the subject to reconsider the answer, or if necessary reminded the subject of the rules determining point values, until the subject was able to determine the correct answer.

Following the instructions teams completed two demonstration trials during which they asked questions and practiced using their response boxes. Four additional practice trials, during which teams were instructed to score as many points as possible, concluded the training session. Subjects were free to communicate with one another during the training session, as well as during all subsequent test sessions.

Each of the four test sessions consisted of eight trials. Each trial consisted of 44 tasks (11 blue triangles, 11 red triangles, 11 blue circles, and 11 red circles), which passed across the screen consecutively (and were surrounded by a buffer of ten tasks in the beginning and eight tasks at the end of the trial, which were not analyzed). Of the 11 tasks of a given color and shape, six were one-person tasks (two A, two B, and two C tasks), three were two-person tasks (one each of AB, AC, and BC tasks), and two were three-person tasks (two ABC tasks). In this way one third of the tasks which a particular participant could be involved in processing were one-person tasks, one third were two-person tasks, and one third were three-person tasks.

In each session, four trials were run under high time stress (TU = 15 seconds) and four trials under moderate time stress (TU = 30 secnds). With high time stress a new task would appear on the left side of the screen every 4.09 seconds, on a randomly choosen free row. The task would move to the right at a uniform rate, and would disappear off the right side of the screen either 45 seconds later, or when it had been successfully processed by the relevant team member(s). Under high time stress processing required 15 seconds, regardless of the task's color, shape, or required workers. With moderate time stress, a new task would appear on the screen every 8.18 seconds, would take 90 seconds to move across the screen, and would require 30 seconds of processing time for completion. The high and moderate time stress conditions were formally equivalent in all respects. That is, even though tasks appeared at a faster rate and moved more quickly across the screen under high time stress, the required processing time was proportionately less so that, theoretically, an equivalent score was possible. Additionally, since display information regarding time was reported in TUs, this information did not vary with time stress.

Across the four test sessions, eight unique random orderings of the 44 tasks were used. Four of these orderings were used for the first two sessions (the first large and first small screen display sessions), and

four were used for the last two sesions (the second large and second small screen display sessions). In this way direct performance comparisons (unconfounded by the particular task orders) could be made as a function of display size, time stress, and their possible interaction.

Although the effect of sessions (the first two versus the second two) were confounded by the particular task orders selected, the use of adjusted performance scores permitted meaningful analyses of these effects. That is, a simple decision model was developed which: (a) noted the tasks which could be completed, (b) listed the possible combinations of these tasks which did not have overlapping required workers, (c) ranked the list of possible combinations according to total point value, and (d) broke ties, if necessary, by selecting the combination which included a task which was closest to leaving the screen. The model, like the subjects, was unaware of any difference between buffer tasks and real tasks. The model's choice of tasks was defined to be the best at that time: no attempt was made to base choices on possible or probable upcoming tasks. The model made each choice at a discrete time and at regular intervals equal to the time required to process a task.

Following the final session all subjects completed a questionnaire on which they rated both the large and small displays as poor, fair, good, or excellent for (a) clarity of presentation, (b) ease of use, and (c) coordination of team effort. In addition, they rated their overall preference, with one indicating a strong preference for the large display and five indicating a strong preference for the small display.

SECTION 3

RESULTS

Analyses of the findings will proceed as follows. First, an analysis of the average points per trial accumulated by the teams will be analyzed as a function of display (large, small), time stress (high, moderate), and session (first, second) with a particular display. Second, the effect of sessions will be reexamined, since it is confounded with task order, after adjusting accumulated points by subtracting the points obtained by the model. Next, some consideration will be given to more fine-grained analyses which examine performance as a function of the number of required workers and the tasks' color and shape, in addition to display, time pressure, and session. Finally, analyses of subjects' questionnaire ratings of the large and small screen displays will be examined.

Analyses of Points

Overall, the size of the display did not influence the average number of points earned by teams, $F(1,7) = .96$, $p = .3588$. When using the large screen display, teams averaged 85.4 points per trial, and when using the individual CRTs they averaged 87.6 points per trial. However, a three-way interaction of display, time pressure, and session which approached significance, $F(1,7) = 4.86$, $p = .0633$, suggested that the display format did have some impact on points accumulated. As inspection of Table 2 reveals, under high time stress and during the first test session with each display format, teams averaged notably fewer points with the large display, 64.3, than with the individual CRTs, 72.5. As expected, time stress had a substantial effect on accumulated points, $F(1,7) = 309.93$, $p = .0000$. Under high time stress teams averaged only 70.0 points per trial, as compared to 102.9 points per trial under moderate stress.

Although it was expected that performance would improve from the first to second session with each display format, no significant effect for session on points per trial emerged, $F(1,7) = 1.37$, $p = .2800$. However, as previously mentioned, the main effect for sessions was confounded with the particular trial task orders used. When raw points are adjusted, by subtracting the points accumulated by the model (an average of 138.25 points for the first session and 130.00 points for the second), a clear improvement in the second session becomes apparent, $F(1,7) = 27.44$, $p = .0012$. Teams averaged 52.95 points fewer than the model in the first session, but only 42.32 points fewer than the model in the second session. Of course, the other results for accumulated points reported previously are unaffected by adjustment to the model.

Analyses of Proportions of Tasks Completed

While the number of points per trial, or adjusted points per trial, is an excellent overall measure of team performance, a more detailed account of behavior is possible by examining the proportion of tasks available which were completed. In this way, one can treat the required number of workers (1, 2, or 3), the color of the task (blue or red), and the shape of the task (triangle or circle) as predictors of task completion along with

display, time stress, and sessions. Such an (2 x 2 x 2 x 3 x 2 x 2) analysis of variance includes an overwhelming number of possible main effects and higher order interactions (63), therefore some selectivity will be used in those presented. First, we will mention some substantial effects which simply demonstrate that teams were sensitive to the properties of the TRAP. Then, effects related to the major focus of this research, display format, will be examined.

Indeed, teams were sensitive to attributes of the TRAP. For example, (a) teams processed 49.0% of the red tasks (high value), but only 13.7% of the blue tasks (low value); (b) teams processed more three-person tasks, 39.8%, than either one-person, 27.9%, or two-person, 26.4%, tasks; and (c) teams processed 57.5% of the three-person triangles, but only 22.1% of the three-person circles, and 35.3% of the one-person circles, but only 20.5% of the one-person triangles. These findings, all highly significant ($p = .0000$), simply demonstrate that the TRAP was meaningful to subjects, and that they behaved in a reasonable manner as they tried to accumulate points. Obviously, (a) more points could be gained by processing red as opposed to blue tasks; (b) team integration and coordination was simplified by processing three-person tasks; and (c) subjects were sensitive to the somewhat complex interaction of shape and required workers in the determination of point value.

Although display format did not significantly influence the overall measure of performance, points per trial, several significant effects involving display format emerge when the proportion of completed tasks is used as the dependent measure. Teams were more sensitive to task color with the individual CRTs than with the large screen display, $F(1,7) = 8.54$, $p = .0223$. Specifically, with the large display teams processed 14.3% of the blue tasks and 47.5% of the red tasks, but with the individual CRTs processed 13.2% of the blue tasks and 50.5% of the red tasks. There was also an interaction of display with task shape, $F(1,7) = 9.73$, $p = .0169$, which was superseded by a three-way interaction which also included session, $F(1,7) = 8.66$, $p = .0216$. The most outstanding characteristic of this interaction is the relatively low proportion of circles completed by teams when tested for the first time with the large screen (See Table 3).

Analyses of Questionnaire Ratings

Following their last test session all twenty-four subjects independently completed a questionnaire asking them to compare the large and small screen displays. The individual CRTs were rated more highly than the large screen (3.54 versus 3.08, respectively) for clarity of presentation, $F(1,23) = 5.28$, $p = .031$. However, the individual CRTs and large screen were not rated significantly different in ease of use (3.33 versus 3.12, $F(1,23) = .75$, $p = .3955$) or for coordination of team effort (2.70 versus 3.08, respectively, $F(1,23) = 2.18$, $p = .1535$). Finally, no significant difference existed in overall preference: eight subjects preferred the large screen, ten preferred the individual CRTs, and six expressed no preference.

TABLE 2. Accumulated Points Per Trial

	High Time Stress		Moderate Time Stress	
	Large Display	Small Displays	Large Display	Small Displays
Session 1	64.3	72.5	102.7	101.7
Session 2	71.8	71.5	102.8	104.6

TABLE 3. Proportion of Completed Tasks as a Function of Display, Shape, and Session

	Large Display		Small Displays	
	Triangle	Circle	Triangle	Circle
Session 1	.350	.249	.333	.308
Session 2	.345	.291	.342	.292

SECTION 4

DISCUSSION

The major purpose of this investigation was to compare team performance on large and small screen, full-color, dynamic, computer-generated displays, using a time-stressed and cognitively complex group problem solving task which required integration and coordination of team members' behavior for optimal team performance. Overall, screen size did not strongly affect team performance in the present research. While teams did respond in a meaningful manner to the properties of the TRAP, their responses were not greatly affected by whether a large shared display or individual CRTs were used. Since the information presented was identical for the two display formats, it may not be surprising that strong differences were not found. While subjects noted many differences between the two display formats (described below), team performance effectiveness was primarily a function of the TRAP parameters used rather than the display format.

Some subtle effects for screen size were found, however, which should not be disregarded. When using individual CRTs teams may have been more sensitive to the color of tasks, since they were then better able to process the more valuable red ones. This effect could be related to subjects' belief that the individual CRTs afforded greater clarity of presentation than the large screen display. Perhaps the strongest indication of potential decrements in performance due to display format occurred during the first test session with the large screen and under high time stress. The relatively low level of team performance found here suggests that teams may need additional training time to adjust to large screen displays before they can be expected to perform optimally in stressful settings.

Subjects were given the opportunity to describe the advantages and disadvantages of the two display formats following the completion of their final test session. Subjects frequently suggested that the large screen display facilitated team communication, but that it was dimmer than the individual displays. Similarly, the individual displays were frequently described as having a sharper picture, but that they tended to isolate the team members and limit interaction. These comments suggest that the different display formats have their own particular advantages and disadvantages which could have canceled each other out in the present study; since the TRAP used required both accurate and timely recognition of task characteristics presented on the display, as well as team communication, coordination, and integration.

An additional comment made by a few subjects suggests an alternative explanation for the previously described (small) performance decrements associated with the large screen display. These subjects indicated that it was more difficult to switch attention back and forth from the large display to the response box, than between the small display and the response box. The similarity of this explanation to the previously discussed alternative explanation of Smith and Duggar's findings adds to

its credibility. When using any display format, it is important to keep in mind the associated and secondary tasks that participants will be required to perform.

The TRAP used in the present research is but a particular instance of a more general research paradigm which can address a host of issues related to team performance in C^3 settings. For example, alternative TRAPs can be formulated which emphasize variables such as multiple resources, uncertainty, risk, expertise, and individual values, through simple modification of various TRAP parameters. In addition, the TRAP paradigm can be used to investigate the importance of different types of feedback information, presentation format, channels of communication, and alternative team member configurations and roles. The fact that subjects in the present study understood and enjoyed the TRAP and responded in a meaningful way to its various manipulated parameters (e.g., time stress, color, and shape), supports the use of the TRAP paradigm for further research efforts.

SECTION 5

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